N94-22317

197525

As previously published in the Combined Optical-Microwave Earth and Atmosphere Sensing Symposium 22-25 March 1993 Albuquerque, New Mexico

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COMPARISON OF CLOUD BOUNDARIES MEASURED WITH 8.6 mm RADAR AND 10.6 μm LIDAR

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INTRODUCTION

One of the most basic cloud properties is location; the height of cloud base and the height of cloud top. The glossary of meteorology defines cloud base (top) as follows: "For a given cloud or cloud layer, that lowest (highest) level in the atmosphere at which the air contains a perceptible quantity of cloud particles" (1). Our studies show that for a 8.66 mm radar, and a 10.6 μm lidar, the level at which cloud hydrometers become "perceptible" can vary significantly as a function of the different wavelengths, powers, beamwidths and sampling rates of the two remote sensors.

THE EXPERIMENT

In November and December of 1991, the First ISCCP Regional Experiment II (FIRE II) was conducted in Coffeyville, Kansas for the purpose of studying cirrus clouds and their effects on planetary radiation budgets. This experiment was a large multi-organizational effort coordinated by NASA. It brought together a large number of surface, airborne, and satellite-based active and passive remote sensors.

The NOAA Wave Propagation Laboratory (WPL) brought a Doppler, 8.66 mm radar (2) and a Doppler, 10.6 μm lidar (3) and operated them side-by-side. Although both instruments have scanning capabilities, they operated primarily in a vertically pointing mode to obtain time-height cross sections of the cloud as it passed over the observation site. The radar pointed in a fixed vertical mode for 25 min of every 30 min observing period. The lidar pointed vertically and also rocked back and forth to determine periods when specular reflection might be occurring. Therefore, the lidar data was filtered in the post processing so that only the vertical beams of data were included in our analysis.

ANALYSIS

To determine echo boundaries from active, range-gated remote sensors, the NOAA/WPL radar group has developed the program CLDSTATS. This program is designed for maximum flexibility so that the user can choose different threshold criteria for determining echo boundaries. This allows CLDSTATS to operate on data sets collected by different remote sensors, as long as the data is in Common Doppler Exchange Format (4). While we have run CLDSTATS primarily on vertically pointing data, the algorithm is sensitive to elevation angle, and in theory can be run on different kinds of scans, for instance RHI scans.

The user specifies a threshold field (e.g. reflectivity), a threshold value, and a minimum number of consecutive range gates in which the threshold value must exist for the in-cloud condition to be met. To choose successful threshold values, the user must have familiarity with the instrument and it's response to backscattering targets in the atmosphere. It should be noted that CLDSTATS examines each beam of data separately, starting at a lower limit and ending at an upper limit which is also user specified. Therefore, this algorithm is a 1-D filter as opposed to similar cloud boundary detection program developed by Penn State University which imposes a 2-D filter (5).

CLDSTATS has been tested extensively on radar data, and we have settled on a thresholding criteria using the normalized coherent power field that appears to work well for all but the must tenuous cirrus clouds. Normalized coherent power is a measure of signal coherence from pulse to pulse. The lidar characterization was somewhat more difficult, since background values of lidar backscatter from aerosols were sometimes as high as in-cloud values. It was therefore necessary to redefine the thresholding levels over even the short time intervals shown in this report.

RESULTS

For this preliminary study, we choose two days during the 1991 FIRE II project to compare cloud boundaries. On November 25, we examined a 1 h 52 min period when a thick stratus deck existed between 3 km and 9 km AGL. Figure 1 shows echo boundaries detected by the radar, and Figure 2 shows echo boundaries detected by the lidar. The radar shows a well defined boundary at both cloud base and cloud top with continuity between consecutive points. The lidar detects cloud base at the same altitude but sees a noisier boundary, with consecutive beams detecting an "in-cloud" condition separated by as much as 350 meters. The lidar echo is clearly attenuated around 6 km, well below the 8-9 km echo top detected by the radar.

These results are summarized in Figures 3 and 4 which show scattergrams of lidar versus radar bases and lidar versus radar tops, respectively. In Figure 3, it can be seen that a certain number of points lie along the 1 to 1 regression line, but the majority of points lie above it. This indicates that the lidar often detects a cloud base higher than that of the radar, sometimes by as much as 750 m. In figure 4, all of the points lie well below the 1 to 1 regression line, some by as much as 4.5 km, indicating that in optically thick clouds, the lidar can greatly underestimate the height of cloud top.

Figures 5 and 6 show radar and lidar echo boundaries for a 5.5 h period on November 26th. On this day, a high, optically thin cirrus formed at around 9 km, and slowly became thicker, with lowering bases throughout the period. The radar and lidar had good agreement on cloud bases throughout a wide range of altitudes (Figure 7). Again, there was a subset of points that lay upon the 1 to 1 regression line, as well as a significant fraction of points above this line, indicating the lidar often detected higher cloud bases, by as much a 1000 m. Figure 8, the scattergram of lidar and radar echo top heights shows a somewhat more surprising result. In this scattergram, a significant number of points lie above the 1 to 1 regression line. This indicates the lidar was seeing a *higher* echo top than the radar. This result has been demonstrated qualitatively using these same data sets by Intrieri et al., (6). They illustrate cases where 1) the lidar signal was attenuated before radar echo top, 2) the lidar detected clouds that were invisible to the radar, and 3) lidar echo tops that were higher than the radar echo tops.

DISCUSSION

There are several measurement factors that contribute to the differences in cloud boundaries detected by the two sensors. These include transmitted wavelength, transmitted power, beamwidth, sampling rate, and range gate spacing.

The effects of beamwidth, sampling rate, and range gate spacing are illustrated in figure 9 which shows a detailed look at a 30 min period. The radar has 0.5° beamwidth, and a pulse length of 37 m, so that by 10 km AGL the sample pulse volume is ~ 2×10^5 m^3. The lidar has a narrower beam, and 75 m pulse length, and therefore the sample pulse volume is only about 60 m^3. The radar pulse repetition frequency (PRF) is 2000 Hz, and in the post processing we further average to 3 sec beams with 6000 samples. The lidar PRF is 4 Hz, and in this study there is no additional averaging in the post processing. Therefore, since the lidar does far less spatial and temporal averaging, it detects rapid, small scale variations in the cloud boundaries that are smoothed by the radar.

The situations where the radar and lidar detect extremely different boundaries, usually involving cloud top is a function of wavelength. Two general scenarios occur; either the lidar signal is attenuated before cloud top by optically thick clouds, or the lidar detects a significantly higher top where it measures backscatter from particles that are too small for the radar to detect. In the extreme case, the lidar detects an entire cloud layer that is invisible to the radar.

CONCLUSION

Clouds have many microphysical and macrophysical properties that affect weather and climate. It would seem cloud boundaries would be one of these properties that would be the most easily observed. However, this paper has shown that the detection of cloud boundaries is not simple, and that different remote sensors can detect significantly different cloud boundaries.

This suggests that the definition of "cloud boundary" needs to be more precise, and may change depending on the application of the information used. For instance, while mm wavelength radars may be sufficient to define cloud boundaries for infrared radiation studies, it is clear that lidars are also necessary to detect very thin cirrus clouds which are important for shortwave radiation studies.

Researchers, particularly in the satellite community must use caution when using a ground-based remote sensor to establish "ground truth" for cloud boundary studies. Optimally, both sensors would be used to determine cloud boundaries for the wide variety of cases that can occur.

ACKNOWLEDGEMENTS

We would like to thank Ed Ash for making software modifications that made this analysis possible. As always, this study would not have been possible without the long hours put in by the FIRE II field crews.

REFERENCES

(1) R.E. Huschke, Editor: Glossary of Meteorology, American Meteorological Society, 1959.

(2) R.A. Kropfli, B.W. Bartram, and S.Y. Matrosov, "The Up-graded WPL dual-polarization 8 mm wavelength Doppler Radar for Microphysical and Climate Research", Proc. Amer. Meteor. Soc. Conf. on Cloud Physics, pp. 341-345, 1990.

(3) M.J. Post, and R.E. Cupp, "Optimizing a Pulsed Doppler Lidar," Appl. Opt., Vol 29, pp. 4145-4153, 1990.

(4) S.L. Barnes, "Report on a Meeting to establish a Common Doppler Radar Data Exchange Format," Bull. Amer. Met. Soc, Vol 61, pp. 1401-1404, 1980.

(5) T. Ackerman, personal communication. 1992.

(6) J.M. Intrieri, W.L. Eberhard, J.B. Snider, and T. Uttal, " Multi-wavelength Observations of a cirrus cloud event from FIRE II: Preliminary Lidar, Radar, and Radiometer Measurements", Proc. Amer. Meteor. Soc. 11th Conf. on Clouds and Precip., Vol 1, pp. 537-540, 1992.

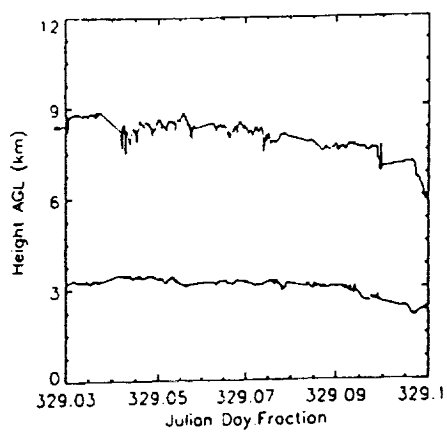

Fig.1 Radar Echo Boundaries November 25, 1991

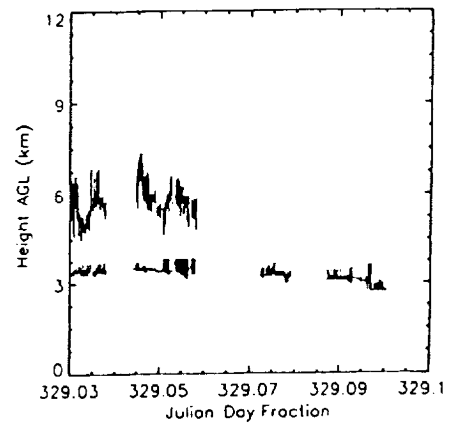

Fig.2 Lidar Echo Boundaries November 25, 1991

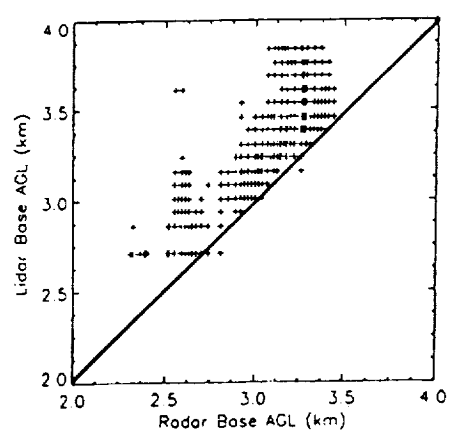

Fig.3 Lidar Base versus Radar Base November 25, 1991

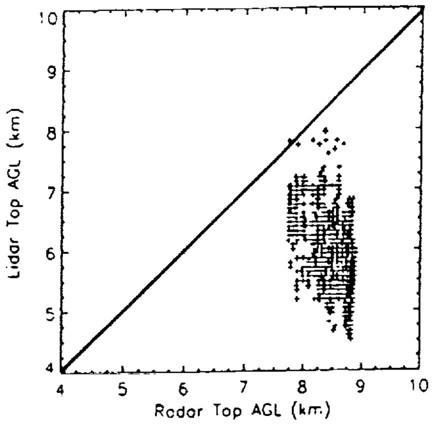

Fig.4 Lidar Top versus Radar Top
November 25, 1991

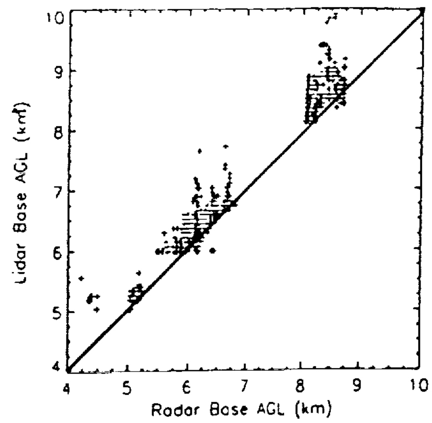

Fig.7 Lidar Base versus Radar Base
November 26, 1991

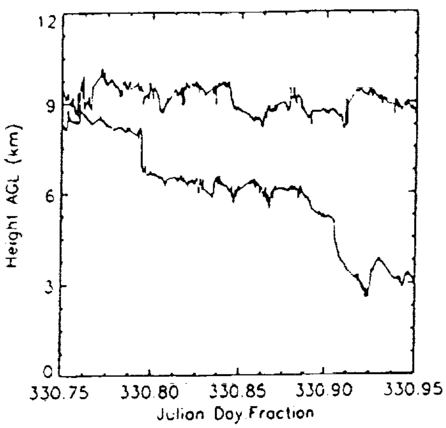

Fig.5 Radar Echo Boundaries
November 26, 1991

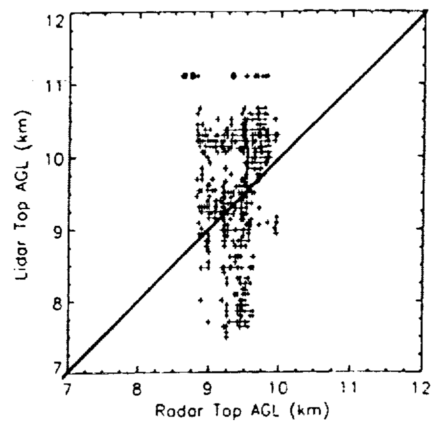

Fig.8 Lidar Top versus Radar Top
November 26, 1991

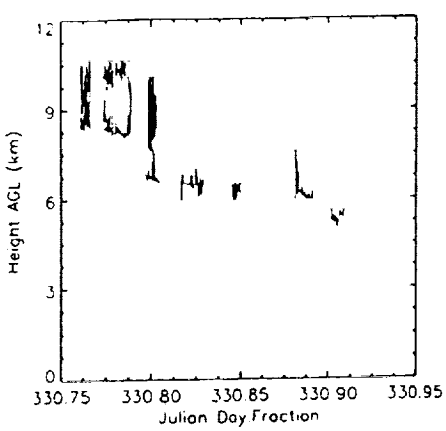

Fig.6 Lidar Echo Boundaries
November 26, 1991

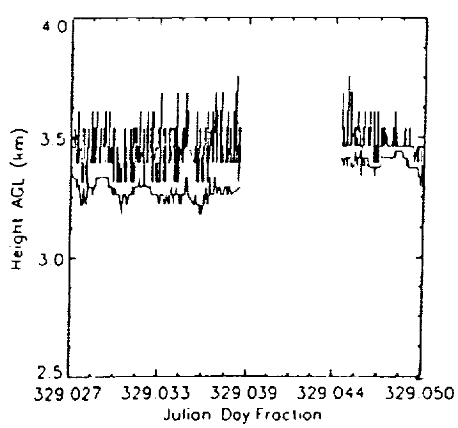

Fig.9 Detail of Radar and Lidar Base
Echoes - Radar Base offset
down 100 m for illustration